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Effect of weathering on the mechanical properties of midribs of coconut leaves

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In the pursuit of newer materials, this paper deals with the characterization of midribs of coconut leaves which form one of the renewable resources of many tropical countries which cultivate coconut trees. The density, chemical constituents and mechanical properties of these midribs are evaluated before and after subjecting them to natural weathering conditions. It is found that cellulose and lignin vary from about 30 and 16% before subjecting to weathering to about 27 and 32%, respectively, after exposure to weathering for 2 years. Alternate wet and dry conditions for 25 cycles result in a decrease of the breaking load of the midrib from 747 to 620 N. These observed properties along with the fracture mechanisms in the midrib are explained on the basis of its structural parameters studied using optical and scanning electron microscopy.

1. Introduction

It is estimated that about 42 million tonnes of coconut leaves are available every year in the world [1]. Each leaf consists of 200 to 250 leaflets, each leaflet being made of a central midrib with two blades on each side [2] (Fig. 1). The length of midribs varies from 0.8 to 1.10 m, with the area of cross-section tapering off from the head position (8.5 mm^2) to the tail (1.0 mm^2). The midrib can be considered to be fibre-like in nature, just like the rest of the coconut tree [3]. The potential of such a vast resource should be explored, though presently it is being used only for brooms or brushes in some of the countries. There have been some serious efforts to find newer resources such as natural fibres and to characterize them for various properties so as to find appropriate applications [3–13]. Also changes in the mechanical properties of coconut leaf thatch subjected to various environmental conditions have been reported [8]. Keeping in mind the pursuit of newer fibres, in this paper the properties of midribs of coconut leaves have been studied before and after exposing them to natural weathering so as to find their potential for various applications. The observed properties have been explained in terms of the chemical composition and structural parameters observed using optical and scanning electron microscopic techniques.

2. Experimental procedure

The midribs were peeled off from the leaflets of coconut leaves, then cleaned thoroughly in running water and dried to a moisture content of about 15%.

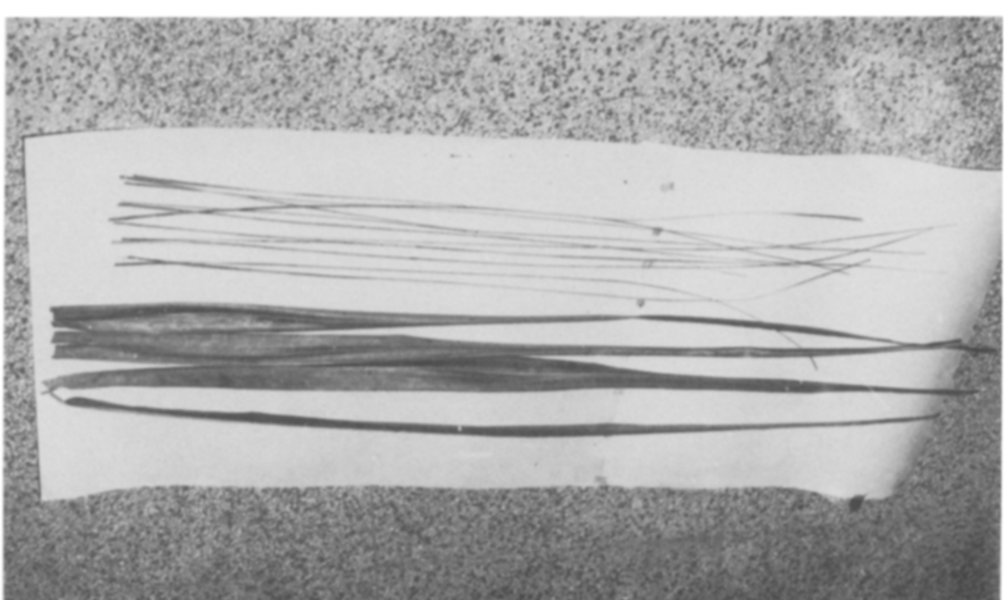

Figure 1 Photograph of a coconut leaflet showing midrib (× 0.05).

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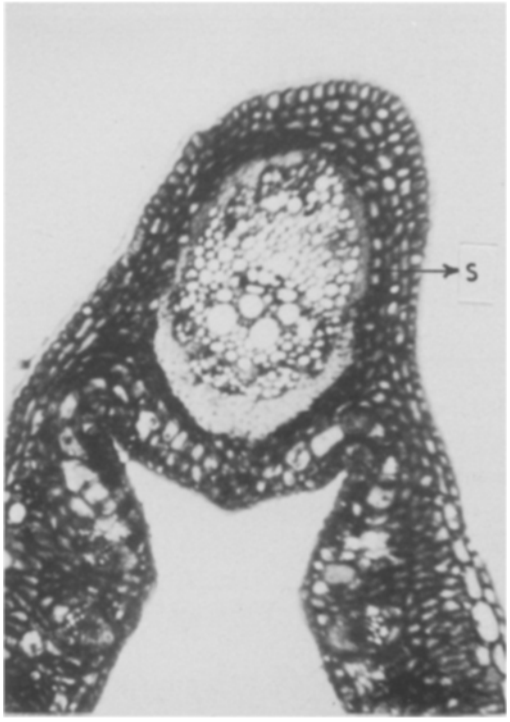

Figure 2 Cross-section of midrib showing arrangement, size and shape of cells. The two protruding portions are parts of the lamina remaining after peeling. S = schlerenchyma cells (× 150).

Preliminary analysis showed that the strength of midribs varied from tree to tree, and from lead to leaf and also in the same midrib from the head portion to the tail portion. Hence, in order to minimize the variation in measured strength between the specimens for a particular experiment, the following procedure was followed in all experiments. Samples of midrib of length 15 cm were cut out leaving 3 cm from the head portion, and the rest rejected. About 500 samples thus made were mixed well and 20 to 25 samples were picked at random for each test and average value computed.

Since the cross-section of midribs was not uniform and circular (Fig. 2) the density of the fibres was used to compute the strength as was done earlier for the fibres. The density of the midrib was determined using a specific gravity bottle with xylene as solvent. All tests were carried out at 65% relative humidity and 25° C.

The tensile properties of 50 mm test length midribs were measured using an Instron testing machine at a strain rate of 2 cm min^{-1}. The effect of weathering was studied by following the decay in strength when the midribs were exposed to natural weathering during the south-western monsoon. The effect of sunlight alone was measured by exposing the midribs to sunlight alone while enclosed in a flat vessel with a glass top. The midribs were also exposed to alternate wet and dry weather by soaking them alternately in water for 2 h and drying for 2 h at 50 to 60° C in an air oven for a number of cycles. In another set of experiments soaking in water was substituted by a shower of force $2.6 \times 10^5 MN m^{-2}$.

Chemical analysis of midribs was carried out before and after exposing them to natural weathering according to ASTM D 1103-60 (reapproved 1977) for alpha cellulose, and ASTM D 1105-56 (reapproved 1977) for lignin.

The structural observations, including the dimensions of individual cells and the cross-sections of midrib and fracture tips, were made using an optical microscope and a Jeol 35C SEM.

3. Results and discussion

Fig. 3 represents a typical stress–strain diagram of the midribs. There is a linear region followed by a smooth but slightly curved portion without a definite yield point. This is similar to that observed in the case of fibres from different parts of coconut tree and also to that of sisal fibre [3, 4]. This indicates that the midrib of coconut leaf is tough but brittle, even though the fracture surface shows a zig-zag or cleavage type with some pull-outs (Fig. 4) as observed in the case of sisal fibre [10].

The initial modulus (IM), ultimate tensile strength (UTS) and percentage elongation of the midribs were evaluated using such stress–strain curves and are

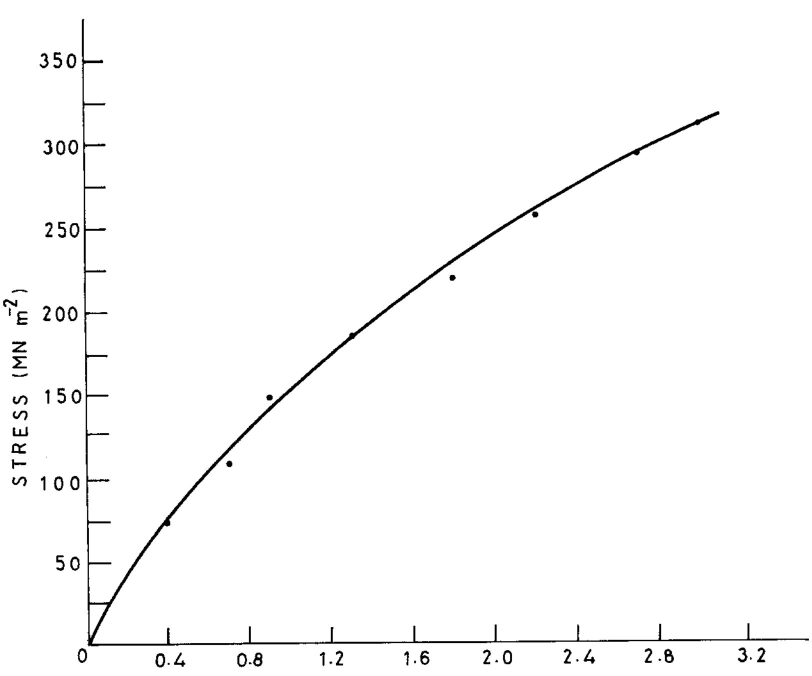

Figure 3 Typical stress–strain curve of midrib.

TABLE I Properties of midribs of coconut leaf and some natural fibres

Fibre	Diameter (μm)	Density ($kg\,m^{-3}$)	Cell dimension l (mm)	l/d	Initial modulus ($GN\,m^{-2}$)	UTS ($MN\,m^{-2}$)	Elongation (%)
Midrib	–	1020	2.27	47	14	170 to 299.74	2 to 3.2
Coir [5]	100 to 450	1150	0.75	35	4 to 6	130 to 175	15 to 47
Palmyrah [12]	70 to 1300	1090	1.30	43	4.4 to 6.1	190	11.0
Talipot [12]	200 to 700	890	1.15	47	9.3 to 13.3	210	3.1
Sisal [10]	50 to 200	1450	2.20	100	9.4 to 15.8	580	4.3

TABLE II Variation in chemical constituents of midribs before and after weathering

Fibre	Holocellulose (%)	α-cellulose (%)	Lignin (%)	Extractives (%)	Ash (%)
Dry fresh midrib	66.50	30.93	16.00	16.87	1.61
Weathered midrib (2 years)	63.77	27.69	32.00	3.42	1.31
Talipot [12]	67.68	48 to 49	28 to 29	3.5 to 4.0	1 to 1.5

listed in Table I along with those of some other natural fibres for comparison. It can be seen that values of modulus, UTS and elongation are comparable to that of talipot fibres. This can be understood from the values of cellulose and lignin content (Table II) as well as the cell dimensions of midribs which are in the range of values for talipot fibres. Also there are more schlerenchyma cells which are thick-walled (Fig. 2) and which also contribute to the strength properties as explained elsewhere [3–13]. In addition, the value of the microfibrillar angle (θ) of midrib derived from a correlation between percentage elongation values seems to be about 20.5°, which is comparable to that of sisal but slightly lower than that of talipot fibre. The value of the modulus derived using this value of θ has been found to be about $12\,GN\,m^{-2}$ which is comparable to the observed value of $14\,GN\,m^{-2}$. This also indicates that initial extension of the midrib involves uncoiling of the crystalline part of the midribs as observed in the case of coir and banana fibre [5, 6].

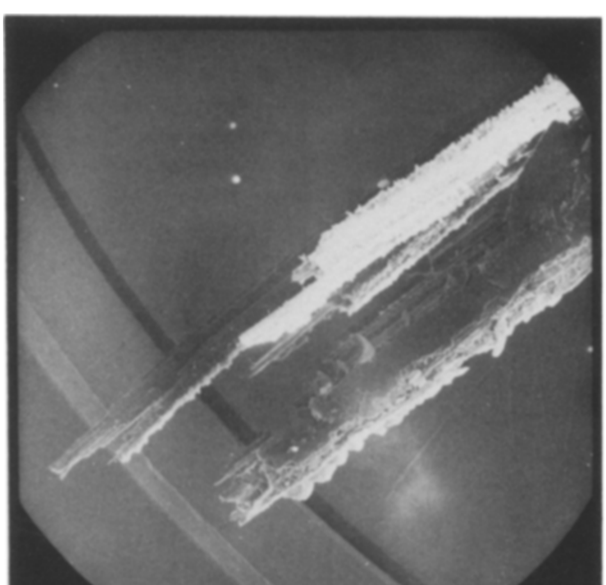

Figure 4 Fractographs of midrib.

Fig. 5 shows the variation of the midrib strength with time after exposure to natural weathering. The exponential decay, reaching a value of $170\,GN\,m^{-2}$ in 150 days with about 56.6% reduction in strength, is in contrast to that of the lamina of the leaf wherein during the same period of exposure the strength was reduced by 90% [8]. Similar results were observed with exposure to sunlight alone. This decrease in strength of midrib on exposure to weathering can be understood in terms of structural changes occurring during this period. While the lignin content of midrib increased from 16% to 32% and the cellulose content decreased from about 31% to 27.7% on exposure (Table II). The surface topography of midribs during weathering showed the erosion of cuticular wax and complete removal of surface layers (Figs 6a to c). Further, the fracture surface of the deteriorated midrib shows brittle fracture (Fig. 7) in contrast to that observed before exposure to weathering (Fig. 4). Microorganisms such as fungi also produce changes in the properties of lignocellulosic materials [14, 15] as observed in coconut leaf thatch [8] when exposed to natural weathering, and this was found to be so even in the case of midrib as can be seen from Fig. 8 which shows the growth of mycelium inside the midribs, possibly indicating the involvement of fungus in the reduction of properties of the midribs.

TABLE III Breaking load of midribs exposed to alternate wet and dry conditions

No. of cycles*	Average breaking load (N)	Sample standard deviation (N)
5	747.56	26.23
10	686.12	26.23
15	641.27	25.6
20	638.80	25.27
25	620.00	24.89
2 h spray and 2 h drying trial, 20 cycles	657.06	25.63

*One cycle is 2 h dip in water followed by 2 h drying.

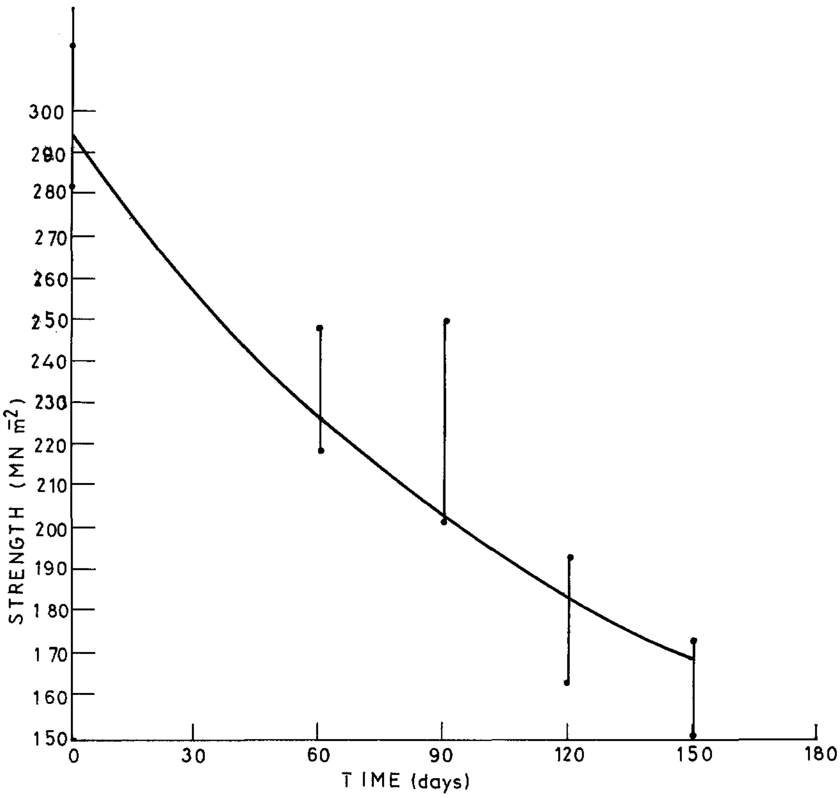

Figure 5 Plot of strength of midrib against time on exposure to natural weathering.

Table III shows the results of alternate wet and dry experiments wherein a decrease in the breaking load of the midribs was observed from about 747 to 620 N in 25 cycles. However, when the spray was used, this decrease was to about 657 N in about 20 cycles. These results point to the fact that alternate wet and dry weather also produces changes in tensile stresses in the midribs contributing to its failure, similar to the behaviour observed in the case of coconut leaf thatch [8].

From the foregoing it becomes apparent that the properties of midribs of coconut leaf are affected by exposure to weathering with the involvement of sunlight, alternate wet and dry conditions and fungus for the deterioration of the strength properties of the midribs. It also appears that an overall embrittlement process is involved in the deterioration of the mechanical properties of midribs on exposure to weathering [16, 17] as observed in the case of coconut leaf thatch [8], even though further studies are needed to ascertain the molecular changes taking place during deterioration.

4. Conclusions

1. The stress–strain curve of the midrib of coconut leaf has been determined for the first time.

2. The major chemical constituents of midrib are found to be cellulose (about 31%) and lignin (about 16%). These values vary on exposure to natural weathering to 27.7% in the case of cellulose and 32.0% for lignin.

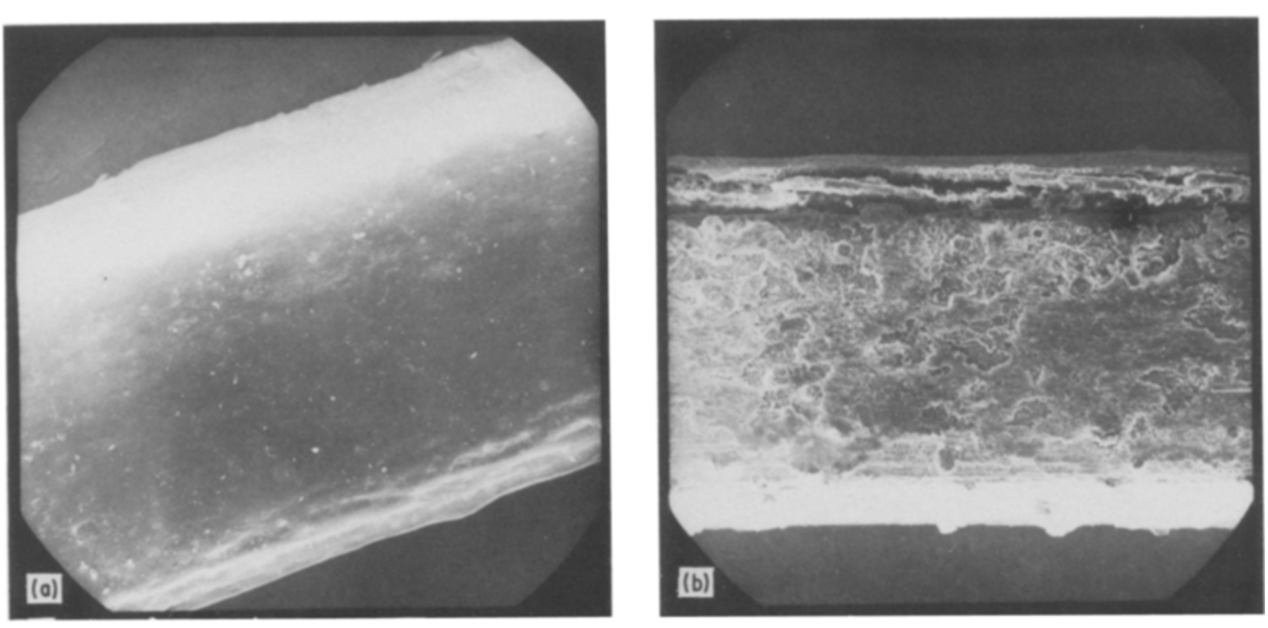

Figure 6 SEM photographs of surface of midrib: (a) before exposure to natural weathering, (b) after exposure to natural weathering for a few months, (c) after extensive exposure to natural weathering (1 year), (d) after exposure to sunlight alone.

Figure 6 Continued

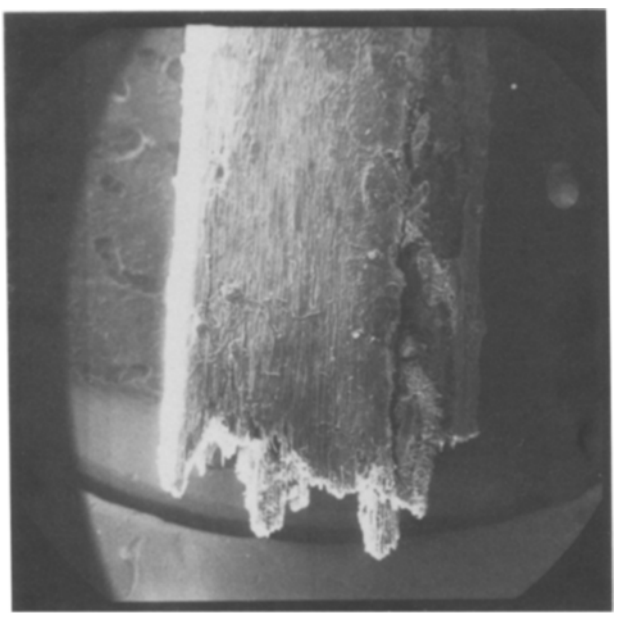

Figure 7 Fractograph of deteriorated midrib.

3. The average values of UTS, initial modulus and percentage elongation of the midrib are found to be in the range of 170 to 299 $MN\,m^{-2}$, 14 $GN\,m^{-2}$ and about 3.5%, respectively. The UTS value is found to decrease by about 56% on exposure to natural weathering for 150 days while the elongation tends almost to zero.

4. The breaking load of the midrib decreased from about 747 to 620 N on exposure to alternate wet and dry weather for 25 cycles.

5. The major factors contributing to changes in the properties of the midrib on exposure to weathering are found to be sunlight, rain, fungus, alternate wet and dry weather and the brittle nature of the midrib itself.

6. The above observed properties of midribs have been satisfactorily explained on the basis of structural parameters such as cell dimension, fracture mechanism and chemical composition.

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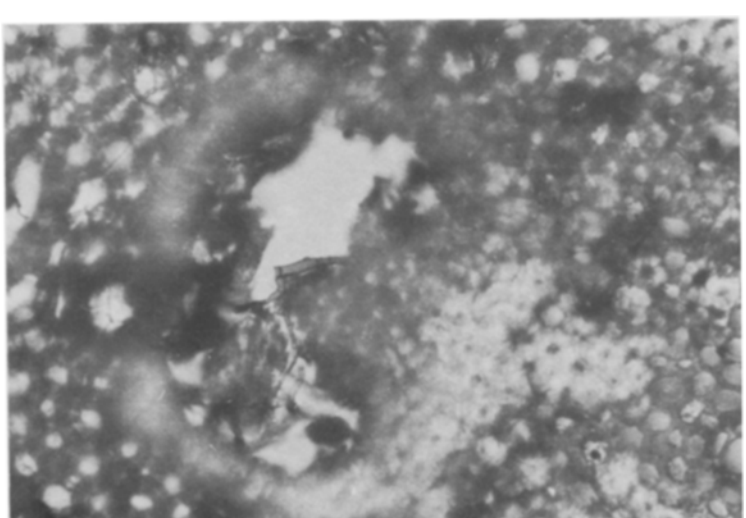

Figure 8 Optical micrograph of deteriorated midrib showing growth of mycelium ($\times$ 150).

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